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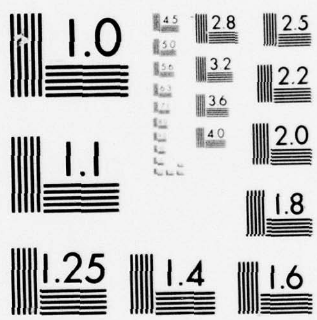

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TECHNICAL REPORT ARLCD-TR-78022

DETERMINATION OF MINIMUM NON-PROPAGATION DISTANCE BETWEEN SEGMENTS OF 105-MM M1 PROJECTILE COMPOSITION B RISER SCRAP

WILLIAM M. STIRRAT

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A series of tests were implemented with 105-mm M1 Projectile Explosive Composition B riser scrap to establish the minimum non-progation distances for four LAP (Load-Assemble-Pack) configurations to be used at the Lone Star Army Ammunition Plant, Texas. The test results indicate that the minimum non-propagation distances are 45.7 centimeters (18 inches) and 91.4 centimeters (36 inches) respectively, for configurations of two and four Composition B scrap risers without funnels, and 61 centimeters (24 inches) and 91.4 centi- over

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meters (36 inches), respectively, for configurations of two and four Composition B scrap risers with shielded funnels. Composition B scrap risers were placed on a conveyor in configurations previously mentioned simulating conditions for a conveyor system to be designed for the LAP facilities at the Lone Star Army Ammunition Plant in Texarkana, Texas.

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SUMMARY

The testing of the 105-mm M1 Projectile Explosive Composition B riser scrap in connection with the Plant Modernization and Expansion Program was requested by ARRADCOM Safety, specifically for the Lone Star Army Ammunition Plant, Texas. The plant, which is presently cast loading the 105-mm projectiles with explosive Composition B, has a riser scrap conveyor system which runs from the funnel pulling operation station back to the riser scrap separation station. A program to determine the minimum non-propagation safe separation distances between various groupings of explosive Composition B riser scrap on a conveyor was undertaken by ARRADCOM and performed at Yuma Proving Ground, Arizona, from April 1975 to November 1977. The tests performed under the auspices of this Program simulated the actual LAP plant conditions.

With the exception of a series of instrumentation check tests, only four test series were performed; namely, on two riser scrap units without zamac funnels, four riser scrap units without funnels, two riser scrap units with funnels and four riser scrap units with funnels.

The first series - two riser scrap units without funnels - established the minimum safe separation distance as 45.7 centimeters (18 inches) with an upper limit of 7.7 percent probability of propagation at a 95 percent confidence level. The second series - four riser scrap units without funnels - established the minimum safe spacing as 91.4 centimeters (36 inches) with an upper limit of 4.7 percent probability of propagation at a 95 percent confidence level. The third series - two riser scrap units contained within their zamac funnels - established the minimum safe spacing at 61.0 centimeters (24 inches) with an upper limit of 5.8 percent probability of propagation at a 95 percent confidence level. The fourth and final series - four riser scrap units contained within their zamac funnels - established the minimum safe spacing as 91.4 centimeters (36 inches) with an upper limit of 6.6 percent probability of propagation at a 95 percent confidence level.

INTRODUCTION

Background

At the present time, the Army-wide expansion program is in process to modernize the existing and to develop new explosive manufacturing and LAP (Load-Assemble-Pack) facilities. This effort will enable said facilities to achieve increased production cost effectiveness with improved safety as well as be able to provide manufacturing facilities for new weaponry with existing facilities. As part of the overall program, the Manufacturing Technology Division of ARRADCOM, Dover, New Jersey, is engaged in the development of safety criteria as an ongoing activity entitled "Safety Engineering in Support of Ammunition Plants." These criteria will be used as part of the data base for the design of future explosive production installations as well as existing facilities scheduled for expansion.

A vital element in this effort is the conveyor design for the transportation of Composition B riser scrap from the 105-mm M1 projectile funnel pulling operation station back to the riser scrap preparation station (Figure 1) at the Lone Star Army Ammunition Plant, Texas. The presently utilized safety manual (Army Materiel Command Regulation AMCR 385-100, Table 17-1) only lists the safe separation distances for ammunition and boxed explosives, and the only prior testing for boxes containing 27.30 kilograms (60 pounds) of flake Composition B indicated a minimum safe non-propagation distance of 3.66 metres (12 feet). The tests described in this report were undertaken to determine the minimum safe non-propagation distance between groupings of Composition B riser scrap on a conveyor system.

Objective

The primary objective of this program was to determine experimentally the safe non-propagative separation distance between various quantities of riser scrap as removed from standard 105-mm M1 projectiles at the funnel pulling section and transported by conveyor to the riser scrap preparation operation and also to determine if commercially available conventional conveyor systems will safely transport the riser scrap material with only simple and economical modifications.

Criteria

The tests were implemented to simulate four actual loading plant configurations employing a conveyor system to transport

Composition B scrap risers between manufacturing operations. The only acceptable criteria to establish the safe clear separation distances for each configuration was the non-propagation of a detonation from a donor unit to the acceptor unit.

Note that the safe separation distances were measured between rubber cleats placed at the edges of the test specimens.

TEST CONFIGURATION

General

Testing of the 105-mm M1 Projectile Composition B riser scrap to determine the appropriate safe non-propagating separation distances between various amounts of riser scrap was initiated in February 1975 at Yuma Proving Ground, Arizona (TPR-MT-F-1899). The Test Program was originally divided into eight phases (Table 1); however, the four phases involving the Amatex 20 explosive were deleted from the Program in April 1977. Each of the four remaining phases, with Composition B explosive, were further divided into exploratory and confirmatory test segments. During the exploratory test segment, tests were conducted at various distances to determine the minimum non-propagative separation spacing, and then using that distance, a number of confirmatory tests were conducted in order to provide enough data for analysis of the probabilities of explosive propagation.

In addition to the four planned phases of this program, an additional three phases, utilizing Composition B riser scrap, were conducted in order to generate an adequate data base for analysis. One phase involved a continuous line of riser scrap, and the other two phases utilized six risers, with and without funnels, to determine their minimum non-propagative separation distance. In these three phases, sufficient quantities of Composition B riser scrap were not available to conduct confirmatory tests.

Extra testing was also conducted in conjunction with Phase 1 to adequately instrument the testing in order to confirm whether or not acceptor units were propagating high or low order, or at all. This testing is listed separately and is not included in the test numbering sequences of any of the phases.

It should also be noted that the various test phases were not conducted in either chronological or phase order. Because of the long time period and large number of tests that were eventually involved in this program, the tests were actually conducted whenever materials, men and proving ground scheduling allowed, and the grouping of test results into related program phases was, of necessity, done later for purposes of data review and analysis.

Test Specimen

Each test specimen consisted of the amount of Composition B riser scrap found on the return conveyor line from the funnel pull operation station on the 105-mm M1 Projectile LAP line.

Dependent upon the test phase, either two (Phases I and V) or four (Phases II and VI) scrap risers were utilized, and the scrap risers were (Phases V and VI) or were not (Phases I and II) encased in funnels.

Each scrap piece of riser tested consisted of approximately 1.13 kilograms (2.50 pounds) of Composition B, which is 60 percent RDX and 40 percent TNT, pre-formed in the shape of the funnel. The funnel (Figure 2) is 27.00 centimeters (10.63 inches) long and varies in diameter from 10.48 centimeters (4.13 inches) down to 4.78 centimeters (1.88 inches) on the outside, with a 0.38-centimeter (0.15-inch) nominal wall thickness, and is made of zamac, a soft zinc alloy.

Test Arrangements

Each test set-up utilized one donor specimen and two acceptor specimens contained in a simulated conveyor system arranged in a straight line. The center specimen served as the donor, while the two specimens at the extremities served as the acceptors. This arrangement produced two acceptor test results for each test donor detonated. The separation distance between donor and acceptor was varied from test to test, but always the same distance from donor to both acceptors was maintained within any given test.

The simulated conveyor system was suspended approximately 40.7 centimeters (16 inches) from the ground by the use of either cinder blocks or used ammunition boxes, whichever was available at the time of the particular test. The simulated conveyor was constructed of pine boards, 2.54 centimeters (1 inch) by 30.50 centimeters (12.0 inches) by 2.44 metres (8.0 feet) for the bottom, with 2.54 centimeters (1.0 inch) by 15.25 centimeters (6.0 inches) by 2.44 metres (8.0 feet) for the sides. The cleats used to separate the riser scrap were standard conveyor belt rubber cleats, 7.62 centimeters (3.0 inches) high and cut to fit the width of the simulated conveyor system. An integral schematic layout of the simulated conveyor test arrangement, as utilized for all phases of the program, is shown in Figure 3.

Method of Initiation

The donor specimen (initiated sample) was primed with approximately 0.12 kilogram (4.0 ounces) of Composition C4 explosive, taken from a M112 demolition block charge and taped in the center of the donor specimen. The Composition C4 explosive was, in turn, initiated by either a Number 8 or an M6 blasting cap energized by

an electric pulse from a standard blasting machine. The blasting machine was located a sufficient distance from the test location to insure adequate safety of observation personnel.

In the phases where the test specimen utilized the zamac funnels, one of the donor specimens had the Composition C4, with blasting cap, taped to its large end on the exposed explosive material.

TEST RESULTS

General

As previously stated, the simulated detonation propagation tests have been grouped into four phases based upon the number of scrap risers used, and whether or not the zamac funnels were used to enclose the Composition B explosive. The results of Phase I, wherein two scrap risers of Composition B without funnels were the test specimens, have been summarized in Table 2. The results of Phase II, wherein four scrap risers of Composition B without funnels were the test specimens, have been summarized in Table 3. The results of Phase V, using two scrap risers enclosed in zamac funnels as test specimens, have been summarized in Table 4. The results of Phase VI, wherein four scrap risers enclosed in zamac funnels were the test specimens, have been summarized in Table 5.

In addition to these pre-planned program phases, a series of unplanned additional testing was conducted to determine the adequacy of the instrumentation and to develop sufficient data to insure confidence in the resultant analysis. First, a series of instrumentation check test results are presented in Table 6, followed by Tables 7 and 8, which summarize the testing of groups of six scrap risers, both with and without the zamac funnels, respectively.

Propagation Detonation Check Tests

During the initial testing conducted in this program, there was a wide difference in observer opinion as to whether an acceptor was just pushed away by the donor detonation or had actually propagated to a high or low order detonation. Since the time period involved was extremely short, and the entire test area was almost immediately obscured by the resultant fireball and smoke cloud, a reliable method of instrumenting the acceptor specimen to determine donor propagation to the acceptors was a necessity. Three presently acceptable testing methodologies were investigated; namely, (a) acceptor initiation of a detonating cord, (2) high-speed motion picture coverage of the test area and (c) the placing of witness plates under each acceptor specimen.

Initially, the use of a detonating cord which would transfer the acceptor detonation to a pine witness board was explored (Figure 4). A total of 14 tests (Table 6) were conducted utilizing this approach to the instrumentation problem. Figure 5 shows the results of the propagation transfer - the detonating cord transfers the acceptor detonation to a witness board; namely, the board is

either broken in half along the path of the detonating cord or is severely splintered along the same path. It was found that the use of a detonating cord did not produce reliable results, as it would indicate a detonation of an acceptor specimen when there was no specimen at the detonating cord's location; namely, the detonating cord itself was too sensitive to the donor detonation.

Next, a series of 15 tests were conducted in which high speed motion pictures (approximately 5,000 frames a minute) were taken of the resultant explosion. In selected cases, both the donor and one of the acceptor specimens would be initiated to a high order detonation in order to get a filmed sample of an acceptor detonation for comparison purposes. Since the qualified film analysis personnel at the Proving Ground could not, with any degree of reliability, identify the initiated acceptor detonations from the known non-detonations of acceptors, this method of instrumenting the safe separation testing of the Composition B Riser Scrap Program was also discontinued.

Finally, a series of tests (five in number) were conducted with steel witness plates located immediately under each acceptor specimen. These plates were 35.6 centimeters (14.0 inches) square by 1.91 centimeters (0.75 inch) thick and made of a mild steel. When an acceptor propagated with a high-order detonation, the witness plate was usually bent and had characteristic blast marks on it (Figure 6); therefore, all of the confirmatory tests in all four phases of the program were conducted with witness plates under the acceptor specimen.

Results of Individual Test Phases

Phase I - Two Scrap Risers Without Funnels (Table 2)

The separation distances used in the exploratory testing of this phase ranged from 7.6 centimeters (3.0 inches) to 244.0 centimeters (96 inches), with a single test (Number 32) being conducted with the scrap risers in intimate contact with each other to check propagation of the detonation. A total of 60 exploratory tests were conducted prior to establishing a separation distance for the confirmatory testing.

Confirmatory testing was performed at a separation distance of 45.7 centimeters (18 inches). A total of 25 confirmatory tests (Numbers 61 to 85 inclusive) were conducted utilizing one donor and two acceptors, thus giving 50 sets of test results for analysis. Three of the confirmatory tests (Numbers 71, 72 and 75) had one side propagate to a low order explosion, and one test (Number 84)

propagated to a high order explosion on one side. These results were discounted from the analysis when it was learned that the amount of Composition C4 explosive used to initiate the donor specimen had been doubled in size. Therefore, the confirmatory tests for Phase I yielded 46 data points for analysis.

Figures 7, 8 and 9 are representative views of the Phase I Test Program. Figure 7 shows the pre-test arrangement of the riser scrap specimens (two per location) on the simulated conveyor for a test where the cleats were not used. Note, in Figure 7, the ignition wire for initiation of the donor specimen. Figure 8 shows the same basic Phase I test arrangement; however, cleats were inserted for this particular test. Figure 9 is a view of the results of Phase I testing. Note the undetonated Composition B riser scrap in the foreground and in the upper part of the figure, indicating non-propagation of the donor detonation.

Phase II - Four Scrap Risers Without Funnels (Table 3)

The separation distances used in the exploratory testing of this program phase ranged from 7.6 centimeters (3.0 inches) to 91.4 centimeters (36.0 inches), with a total of 36 exploratory tests (Numbers 1 to 36 inclusive) being conducted prior to establishing a separation distance for the confirmatory tests.

The confirmatory testing was performed at a separation distance of 91.7 centimeters (36.0 inches). A total of 30 confirmatory tests (Numbers 37 to 66 inclusive) were conducted utilizing one donor and two acceptors, thus again producing 60 sets of test results for analysis. In addition to these confirmatory tests, the resultant data from Test Numbers 13 to 20 inclusive (8 tests or 16 data points) can be included in the resultant data analysis since they were also conducted at a separation distance of 91.4 centimeters (36.0 inches).

Figure 10 shows one of the test arrangements utilized for Phase II testing and Figure 11 demonstrates the post-test acceptor riser scrap indicating non-propagation of the donor detonation.

Phase V - Two Scrap Risers with Funnels (Table 4)

The spacing distances utilized in the exploratory testing of this program phase ranged from 30.5 centimeters (12.0 inches) to 48.7 centimeters (19.2 inches), measured from rubber cleat to rubber cleat, with a total of 11 exploratory tests (Numbers 1 to 11 inclusive) being conducted prior to establishing a safe separation distance for the confirmatory tests.

The confirmatory testing was performed at a safe separation distance of 61.0 centimeters (24.0 inches). A total of 31 confirmatory tests (Numbers 12 to 42 inclusive) were conducted using the one donor - two-acceptor system, thus producing 62 test observations for analysis.

Figure 12 is an end view of the test arrangements utilized for Phase V tests and Figure 13 is a closeup of the acceptor units after the high order detonation of the donor.

Phase VI - Four Scrap Risers with Funnels (Table 5)

The separation distances utilized in the exploratory testing of this program phase ranged from 45.7 centimeters (18.0 inches) to 48.7 centimeters (19.2 inches), measured from rubber cleat to rubber cleat, with a total of 10 exploratory tests (Numbers 1 to 10 inclusive) being conducted prior to establishing a safe separation distance for the confirmatory tests.

Initially, a series of confirmatory tests were conducted at a safe separation distance spacing of 61.0 centimeters (24 inches). This series included Test Numbers 11 to 39 inclusive, or a total of 29 tests using the one donor - two-acceptor system and producing 58 test data observations. However, within this test series, there were seven high order detonations of acceptor units, thus negating the value of the test results.

The final confirmatory tests were performed at a safe separation distance of 91.4 centimeters (36 inches). A total of 25 confirmatory tests (Numbers 40 to 64 inclusive) were conducted, again using the one donor - two-acceptor system, and thus producing 50 test data observations for safety analysis. In addition, the resultant data from Test Numbers 3 and 4 (also conducted at 91.4 centimeters (36 inches) or four additional test data observations can be included in the analysis since these tests were also conducted at the 91.4-centimeter (36-inch) separation distance.

Figure 14 is an end view of the test arrangements utilized for Phase VI tests and Figure 15 is a post-test closeup of the acceptor units, showing both riser scrap and rubber cleats.

Results of Unprogrammed Test Series

In addition to the four test phases as discussed above, three unprogrammed test series were conducted since an adequate supply of riser scrap and other test material was readily available, and the additional data would provide additional safe separation study information for use in ammunition plant construction

safety criteria. The three test series were: (1) a continuous line of scrap risers, (2) standard test procedure with six scrap risers within funnels at each location and (3) standard test procedure with six scrap risers at each location.

As a remote possibility, a continuous line of Composition B scrap risers coming from the funnel pull operation were tested. On a simulated conveyor line, a continuous line of scrap risers, all in intimate contact with each other, 1.83 meters (6.0 feet) long was set up and the center two scrap risers were initiated high order. The resultant detonation propagated to all the riser scrap in both directions, fully consuming all the explosive material.

Next, a series of tests were conducted on simulated conveyors utilizing groupings of six risers within funnels, each for the donor and acceptor specimen. A total of six tests were performed (Table 7) at separation distances ranging from 3.37 metres (11.0 feet) to 7.65 metres (25.0 feet). In none of the tests was there any propagation of the donor detonation to the acceptors.

The final test series was also conducted on simulated conveyors. This time, again utilizing groupings of six risers only, without funnels, for the donor and acceptor specimen (Figure 16), a total of 11 tests were performed (Table 8) at separation distances ranging from 30.5 centimeters (12.0 inches) to 60.0 centimeters (24.0 inches), with propagations of the donor detonation occurring at all separation distances tested.

<u>Summary of Test Results</u>

The confirmatory test results clearly showed that no propagation of detonations occurred at the established safe clear separation distances. The established safe clear separation distances for groupings of two and four scrap risers without funnels (Phases I and II). were 45.7 centimeters (18 inches) and 91.4 centimeters (36 inches), respectively.

The established safe clear distances for groupings of Two and Four Scrap Risers with Funnels (Phases V and VI), respectively, were 61 centimeters (24 inches) and 91.4 centimeters (36 inches).

The results of the unprogrammed test series demonstrated that configurations of six Composition B scrap risers in intimate contact with each other, each configuration for the donor and acceptor specimen, positioned on a simulated conveyor cannot be considered until further testing is implemented. The safe clear distances for groupings of six Composition B scrap risers within

funnels may not be compatible with normal belt conveyor speeds. Propagation of donor detonation occurred at all separation distances tested for groupings of six Composition B scrap risers without funnels.

Analysis of Confirmatory Test Results

Variations in manufacturing tolerances, materials, wear, etc., require that statistical reasoning be enlisted in the interpretation of the test data. The actual probability of the propagation of an explosive incident is a function of the number of propagation occurrences in a particular test phase as related to the total number of tests conducted (see Appendix for statistical theory).

In Test Phase I, where each specimen was two scrap risers without funnels, there was a total of 46 observations at the 45.7-centimeter (18-inch) safe separation distance which yielded usable data for analysis. Certain data points were considered invalid since the test set-up had been slightly altered, thus negating that run's data. Therefore, the upper limit on the probability of propagation is 7.7 percent at the 95 percent confidence level.

In Test Phase II, where each specimen was four scrap risers without funnels, there was a total of 76 observations at the 91.4-centimeter (36-inch) safe separation distance which yielded usable data for analysis. In this case, the upper limit on the probability of propagation of an accidental detonation to an adjacent specimen is 4.7 percent at the 95 percent confidence level.

In Phase V, where two scrap risers of Composition B with loading funnels were spaced at 61.0 centimeters (24 inches) between rubber cleats, a total of 62 data observations were recorded, resulting in an upper limit of 5.8 percent probability of propagation of an explosive incident at the 95 percent confidence level.

In Phase VI, where four risers of explosive Composition B with loading funnels were spaced at 91.4 centimeters (36 inches) between rubber cleats, a total of 54 data observations were recorded, resulting in an upper limit of 6.6 percent probability of propagation of an explosive incident at the 95 percent confidence level.

These values are equivalent to stating that in a large number of tests, 95 out of a 100 times, the probability of an explosive event will be less than or equal to the stated values. These values indicate the quality of the tests and the reliance that can be placed upon the conclusions drawn from the testing (see Figure 17).

CONCLUSIONS

A sufficiently large sample size of 105-mm M1 Projectile Composition B riser scrap was tested in each of the four potential configurations (two versus four risers, with or without funnels) in order to determine the minimum safe separation distances for loading plant design. The minimum safe spacing for two scrap risers without the shielding funnels was 45.7 centimeters (18 inches), and for the four scrap risers without funnels, 91.4 centimeters (36.0 inches).

For two Composition B risers contained within funnels, the safe separation distance was 61.0 centimeters (24 inches) and for four Composition B risers contained within funnels, the safe separation distance was 91.4 centimeters (36 inches).

TABLE 1

105-mm M1 projectile riser scrap
Test program outline

Phase	No. of Risers	Explosive	Number of Tests: Exploratory	Number of Tests: Confirmatory
I	2	Comp B	8	25
II	4	Comp B	8	25
III	2	Amatex 20	8	25
IV	4	Amatex 20	8	25
V	2 with funnels	Comp B	8	25
VI	4 with funnels	Comp B	8	25
VII	2 with funnels	Amatex 20	8	25
VIII	4 with funnels	Amatex 20	8	25

TABLE 2

Test results (Phase I - 2 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
1	61.0	(21)	No	No cleats used.
2	30.5	(12)	No	No cleats used.
3	15.3	(6)	No	No cleats used.
4	7.6	(3)	No	No cleats used.
5	7.6	(3)	No	No cleats used.
6	7.6	(3)	Yes	Two cleats between each acceptor and donor.
7	15.3	(6)	Yes	Two cleats between each acceptor and donor.
8	15.3	(6)	Yes	
9	15.3	(6)	Yes	No cleats used.
10	30.5	(12)	Yes	Low order.
11	30.5	(12)	Yes	Low order.
12	30.5	(12)	Yes	Low order.
13	45.7	(18)	Yes	
14	91.4	(36)	Yes	
15	91.4	(36)	Yes	Low order, one side only.
16	122.0	(48)	Yes	Low order, one side only.
17	91.4	(36)	No	Cleats found.
18	244.0	(96)	No	
19	213.0	(84)	No	Cleats damaged.
20	183.0	(72)	Yes	Low order, one side only.

TABLE 2
(continued)

Test results (Phase I - 2 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
21	183.0	(72)	No	
22	152.5	(60)	No	
23	122.0	(48)	No	
24	122.0	(48)	No	
25	122.0	(48)	No	
26	122.0	(48)	No	
27	122.0	(48)	No	
28	122.0	(48)	No	
29	91.4	(36)	No	
30	30.5	(12)	No	
31	15.6	(6)	No	
32	0	0	Yes	
33	30.5	(12)	No	
34	30.5	(12)	No	
35	30.5	(12)	No	
36	30.5	(12)	Yes	Both sides.
37	30.5	(12)	No	
38	30.5	(12)	Yes	One side only.
39	30.5	(12)	No	
40	30.5	(12)	Yes	One side only.

TABLE 2
(continued)

Test results (Phase I - 2 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
41	76.3	(30)	Yes	One side only.
42	76.3	(30)	No	
43	91.4	(36)	No	
44	91.4	(36)	No	
45	91.4	(36)	No	
46	91.4	(36)	No	
47	91.4	(36)	No	
48	91.4	(36)	Yes	One side only.
49	122.0	(48)	No	
50	122.0	(48)	No	
51	122.0	(48)	No	
52	122.0	(48)	No	
53	122.0	(48)	No	
54	122.0	(48)	No	
55	122.0	(48)	No	
56	122.0	(48)	No	
57	122.0	(48)	Yes	One side only.
58	122.0	(48)	No	
59	122.0	(48)	No	
60	122.0	(48)	No	

TABLE 2
(continued)

Test results (Phase I - 2 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
61	45.7	(18)	No	
62	45.7	(18)	No	
63	45.7	(18)	No	
64	45.7	(18)	No	
65	45.7	(18)	No	
66	45.7	(18)	No	
67	45.7	(18)	No	
68	45.7	(18)	No	
69	45.7	(18)	No	
70	45.7	(18)	No	
71	45.7	(18)	Yes	Low order, one side only.
72	45.7	(18)	Yes	Low order, one side only.
73	45.7	(18)	No	
74	45.7	(18)	No	
75	45.7	(18)	Yes	Low order, one side only.
76	45.7	(18)	No	
77	45.7	(18)	No	
78	45.7	(18)	No	
79	45.7	(18)	No	
80	45.7	(18)	No	

TABLE 2
(concluded)

Test results (Phase I - 2 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
81	45.7	(18)	No	
82	45.7	(18)	No	
83	45.7	(18)	No	
84	45.7	(18)	Yes	One side HIGH ORDER.
85	45.7	(18)	No	

NOTE: Test numbers 70 to 85 inclusive accidentally utilized a double booster charge.

PHASE I
(continued)

TEST SET-UP

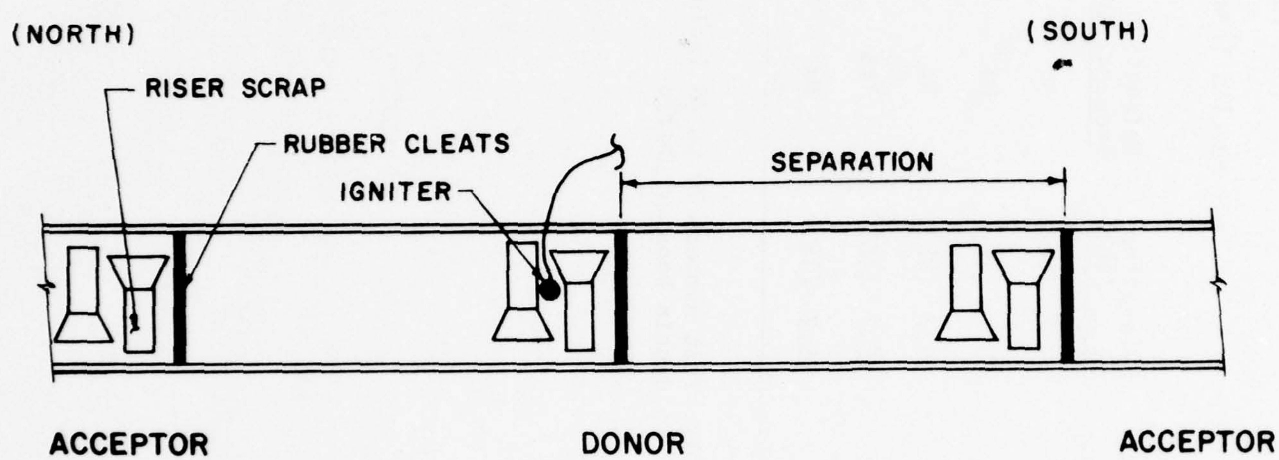


TABLE 3

Test results (Phase II - 4 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
1	15.3	(6)	No	No cleats used.
2	7.6	(3)	No	No cleats used.
3	7.6	(3)	No	No cleats used.
4	15.3	(6)	Yes	Two cleats between each acceptor and donor.
5	30.5	(12)	Yes	Two cleats between each acceptor and donor. One side only.
6	30.5	(12)	No	
7	30.5	(12)	No	
8	15.3	(6)	Yes	One side only.
9	45.7	(18)	No	
10	45.7	(18)	Yes	One side only.
11	45.7	(18)	No	
12	45.7	(18)	No	
13	91.4	(36)	No	
14	91.4	(36)	No	
15	91.4	(36)	No	
16	91.4	(36)	No	
17	91.4	(36)	No	
18	91.4	(36)	No	
19	91.4	(36)	No	

TABLE 3
(continued)

Test results (Phase II - 4 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
20	91.4	(36)	No	
21	76.3	(30)	Yes	Low order, one side only.
22	76.3	(30)	Yes	High order, one side only.
23	76.3	(30)	No	
24	76.3	(30)	No	
25	76.3	(30)	No	
26	76.3	(30)	No	
27	76.3	(30)	Yes	Low order, one side only.
28	76.3	(30)	No	
29	76.3	(30)	No	
30	76.3	(30)	No	
31	76.3	(30)	No	
32	76.3	(30)	No	
33	76.3	(30)	Yes	High order, one side only.
34	76.3	(30)	No	
35	76.3	(30)	No	
36	76.3	(30)	Yes	High order, one side only.
37	91.4	(36)	No	
38	91.4	(36)	No	
39	91.4	(36)	No	

TABLE 3
(continued)

Test results (Phase II - 4 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
40	91.4	(36)	No	
41	91.4	(36)	No	
42	91.4	(36)	No	
43	91.4	(36)	No	
44	91.4	(36)	No	
45	91.4	(36)	No	
46	91.4	(36)	No	
47	91.4	(36)	Yes	Low order, one side only.
48	91.4	(36)	No	
49	91.4	(36)	No	
50	91.4	(36)	No	
51	91.4	(36)	No	
52	91.4	(36)	No	
53	91.4	(36)	No	
54	91.4	(36)	No	
55	91.4	(36)	No	
56	91.4	(36)	No	
57	91.4	(36)	No	
58	91.4	(36)	Yes	Low order, one side only.

TABLE 3
(concluded)

Test results (Phase II - 4 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
59	91.4	(36)	Yes	High order, donor had extra booster (accidentally).
60	91.4	(36)	Yes	Low order, one side only.
61	91.4	(36)	No	
62	91.4	(36)	No	
63	91.4	(36)	No	
64	91.4	(36)	Yes	High order, same as No. 59.
65	91.4	(36)	No	
66	91.4	(36)	No	

TABLE 4

Test results (Phase V - 2 risers w/funnels)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
1	30.5	(12)	Yes	No cleats used. Low order, one side only.
2	61.0	(24)	Yes	No cleats used. Low order on both sides.
3	45.7	(18)	Yes	No cleats used. Low order, one side only.
4	122.0	(48)	Yes	No cleats used. Low order, one side only.
5	244.0	(96)	No	No cleats used.
6	244.0	(96)	Yes	Low order, one side only.
7	365	(144)	No	
8	487	(192)	No	
9	45.7	(18)	No	
10	45.7	(18)	Yes	Low order, one side only.
11	45.7	(18)	Yes	High order, both sides.
12				
13	61.0	(24)	No	
14	61.0	(24)	No	
15	61.0	(24)	No	
16	61.0	(24)	No	
17	61.0	(24)	No	
18	61.0	(24)	No	

TABLE 4
(continued)

Test results (Phase V - 2 risers w/funnels)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
19	61.0	(24)	No	
20	61.0	(24)	No	
21	61.0	(24)	No	
22	61.0	(24)	No	
23	61.0	(24)	No	
24	61.0	(24)	No	
25	61.0	(24)	No	
26	61.0	(24)	Yes	High order, excessive donor booster charge (accidentally).
27	61.0	(24)	No	
28	61.0	(24)	No	
29	61.0	(24)	No	
30	61.0	(24)	No	
31	61.0	(24)	No	
32	61.0	(24)	No	
33	61.0	(24)	No	
34	61.0	(24)	No	
35	61.0	(24)	No	
36	61.0	(24)	No	
37	61.0	(24)	No	

TABLE 4
(concluded)

Test results (Phase V - 2 risers w/funnels)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
38	61.0	(24)	No	
39	61.0	(24)	No	
40	61.0	(24)	No	
41	61.0	(24)	No	
42	61.0	(24)	No	

TABLE 5

Test results (Phase VI - 4 risers w/funnels)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
1	244.0	(96)	No	
2	487.0	(192)	No	
3	91.4	(36)	No	
4	91.4	(36)	No	
5	76.3	(30)	No	
6	76.3	(30)	No	
7	61.0	(24)	No	
8	61.0	(24)	No	
9	61.0	(24)	No	
10	45.7	(18)	Yes	High order, one side only.
11	61.0	(24)	No	
12	61.0	(24)	No	
13	61.0	(24)	No	
14	61.0	(24)	No	
15	61.0	(24)	No	
16	61.0	(24)	No	
17	61.0	(24)	No	
18	61.0	(24)	No	
19	61.0	(24)	No	
20	61.0	(24)	No	
21	61.0	(24)	No	

TABLE 5
(continued)

Test results (Phase VI - 4 risers w/funnels)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
22	61.0	(24)	No	
23	61.0	(24)	No	
24	61.0	(24)	No	
25	61.0	(24)	No	
26	61.0	(24)	No	
27	61.0	(24)	No	
28	61.0	(24)	No	
29	61.0	(24)	No	
30	61.0	(24)	Yes	High order, both sides.
31	61.0	(24)	No	
32	61.0	(24)	Yes	High order, one side only.
33	61.0	(24)	No	
34	61.0	(24)	Yes	High order, both sides.
35	61.0	(24)	No	
36	61.0	(24)	Yes	High order, both sides.
37	61.0	(24)	No	
38	61.0	(24)	No	
39	61.0	(24)	No	
40	91.4	(36)	No	
41	91.4	(36)	No	

TABLE 5
(continued)

Test results (Phase VI - 4 risers w/funnels)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
42	91.4	(36)	No	
43	91.4	(36)	No	
44	91.4	(36)	No	
45	91.4	(36)	No	
46	91.4	(36)	No	
47	91.4	(36)	No	
48	91.4	(36)	No	
49	91.4	(36)	No	
50	91.4	(36)	No	
51	91.4	(36)	No	
52	91.4	(36)	No	
53	91.4	(36)	No	
54	91.4	(36)	No	
55	91.4	(36)	No	
56	91.4	(36)	No	
57	91.4	(36)	No	
58	91.4	(36)	No	
59	91.4	(36)	No	
60	91.4	(36)	No	
61	91.4	(36)	No	

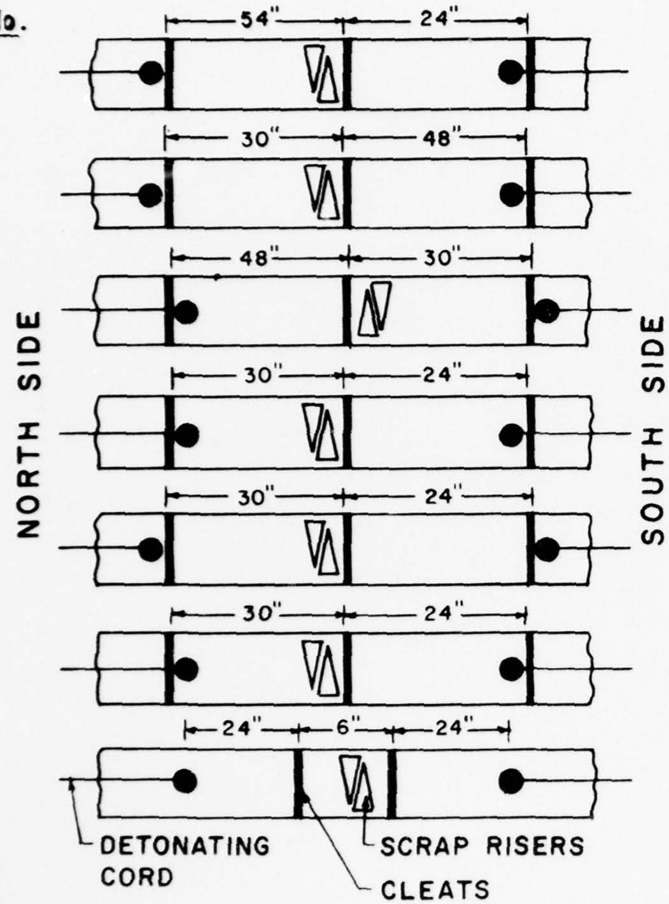
TABLE 5
(concluded)

Test results (Phase VI - 4 risers w/funnels)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
62	91.4	(36)	No	
63	91.4	(36)	No	
64	91.4	(36)	No	

TABLE 6

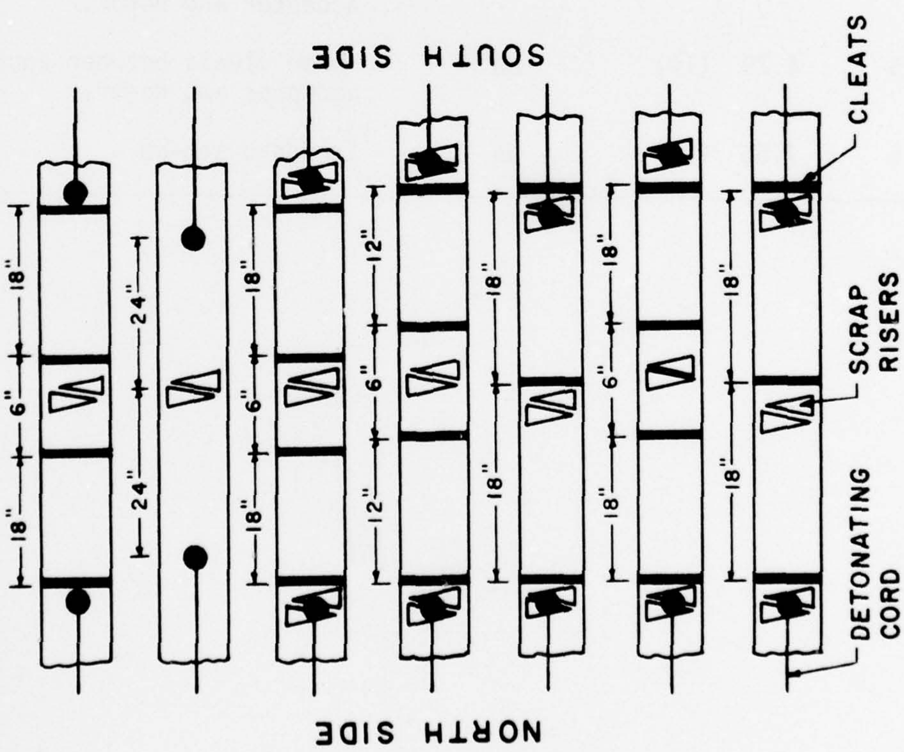
Test results (Check tests)



Test No.	Results
1	High Order detonation, south only
2	High Order detonation, south only
3	High Order detonation, north only
4	High Order detonation, south only
5	No detonation propagation
6	High order detonation, south only
7	High order detonation, both sides

TABLE 6

Test results (Check tests)
(concluded)



Test No.	Results
8	No detonation propagation
9	No detonation propagation
10	No detonation propagation
11	No detonation propagation
12	No detonation propagation
13	No detonation propagation
14	No detonation propagation

TABLE 7

Test results (6 risers w/funnels)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
1	6.12	(20)	No	No cleats used, some penetration.
2	3.37	(11)	No	Two cleats between each acceptor and donor. Minor penetration.
3	4.29	(14)	No	Three cleats between each acceptor and donor.
4	4.29	(14)	No	Three cleats between each acceptor and donor.
5	4.29	(14)	No	Three cleats between each acceptor and donor.
6	7.65	(25)	No	Standard set-up.

TABLE 8

Test results (6 risers)

Test No.	Separation cm	(in)	Detonation Propagation	Remarks
1	30.5	(12)	No	No cleats used.
2	30.5	(12)	Yes	Two cleats between each acceptor and donor. High order, one side.
3	30.5	(12)	Yes	Two cleats between each acceptor and donor. High order, one side.
4	61.0	(24)	No	Two cleats between each acceptor and donor.
5	57.2	(22.5)	Yes	Two cleats between each acceptor and donor. Low order, one side.
6	50.8	(20)	No	Two cleats between each acceptor and donor.
7	38.2	(15)	Yes	Two cleats betwen each acceptor and donor. High order, one side.
8	44.5	(17.5)	Yes	Two cleats between each acceptor and donor. High order, one side.
9	61.0	(24)	No	No cleats used.
10	61.0	(24)	No	No cleats used.
11	61.0	(24)	Yes	No cleats used. High order, one side.

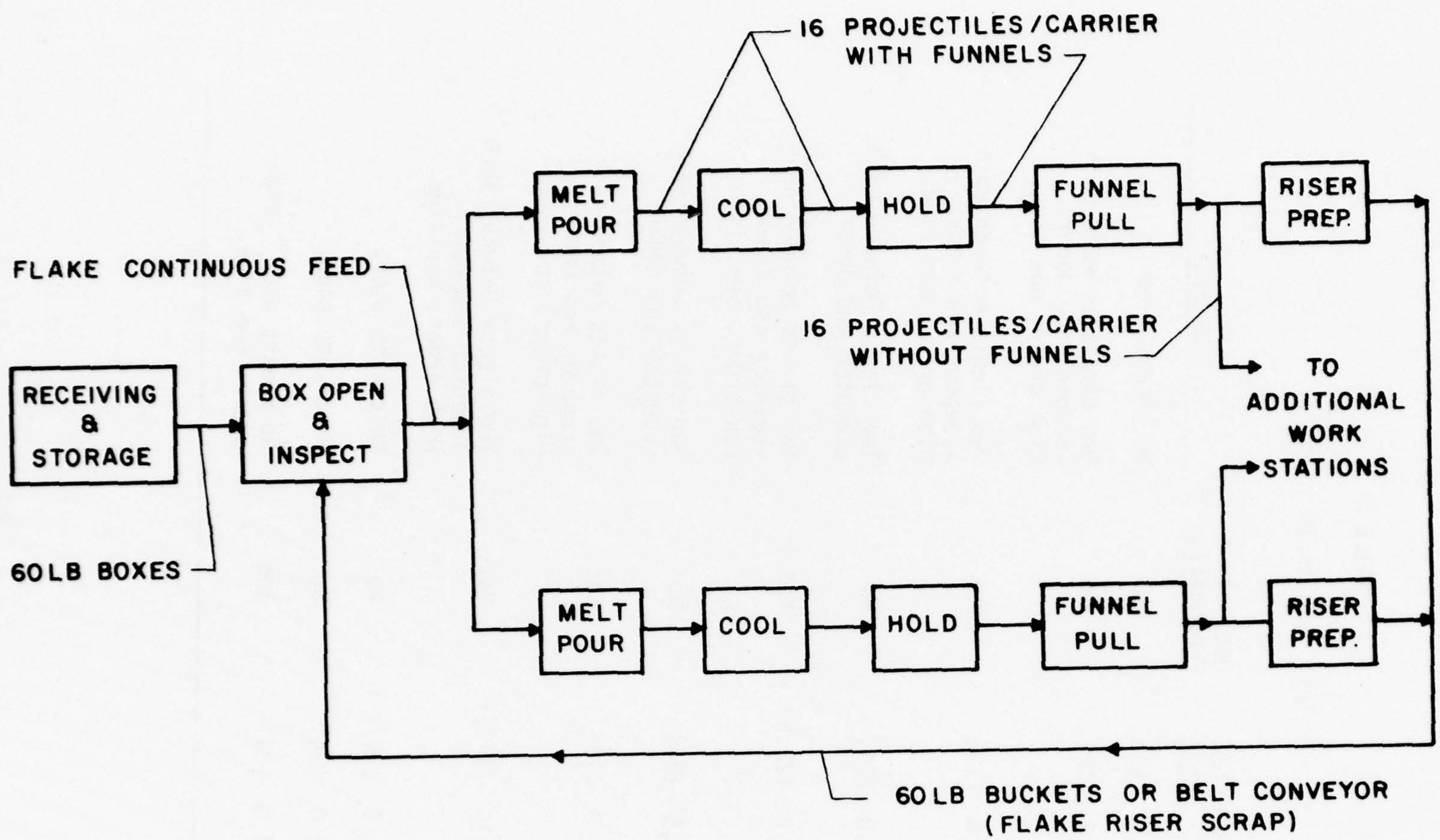


Fig 1 105-mm M1 Projectile melt/pour flow diagram

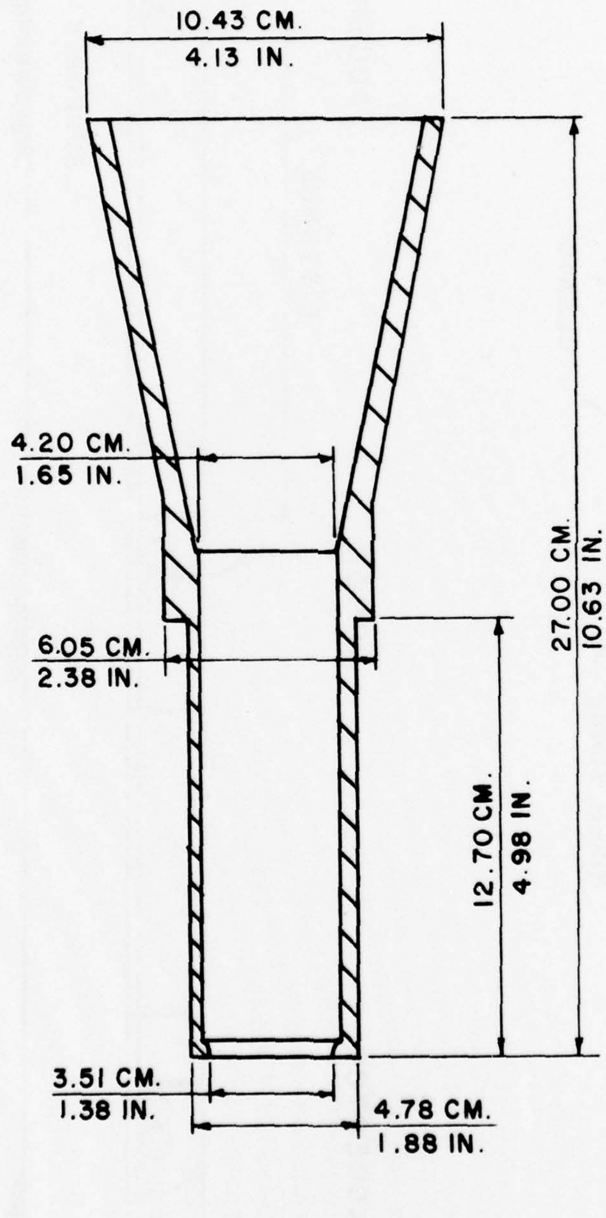


Fig 2 Riser scrap funnel

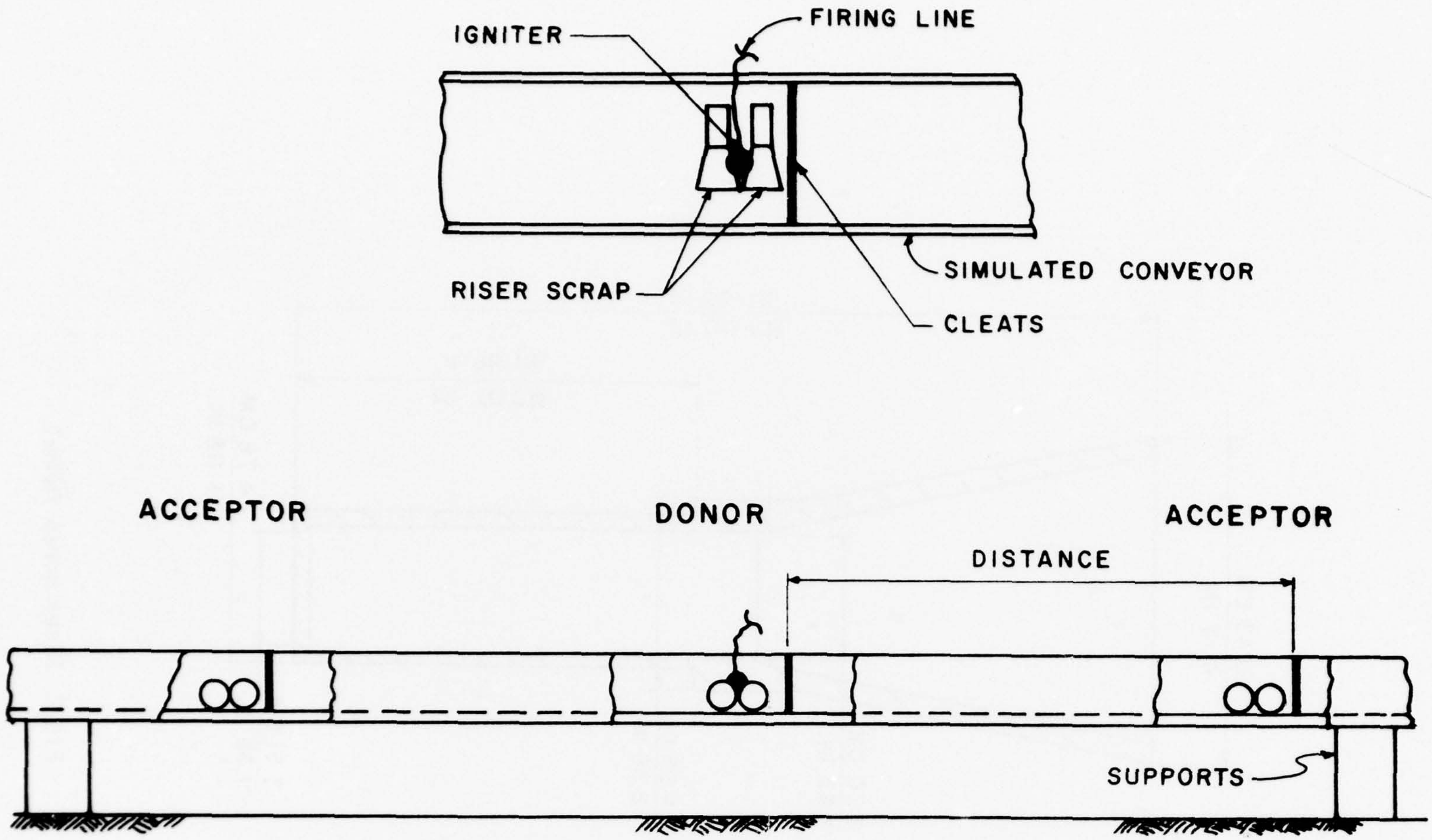


Fig 3 Test set-up for conveyor riser scrap program

Fig 4 Test set-up for propagation detonation check tests

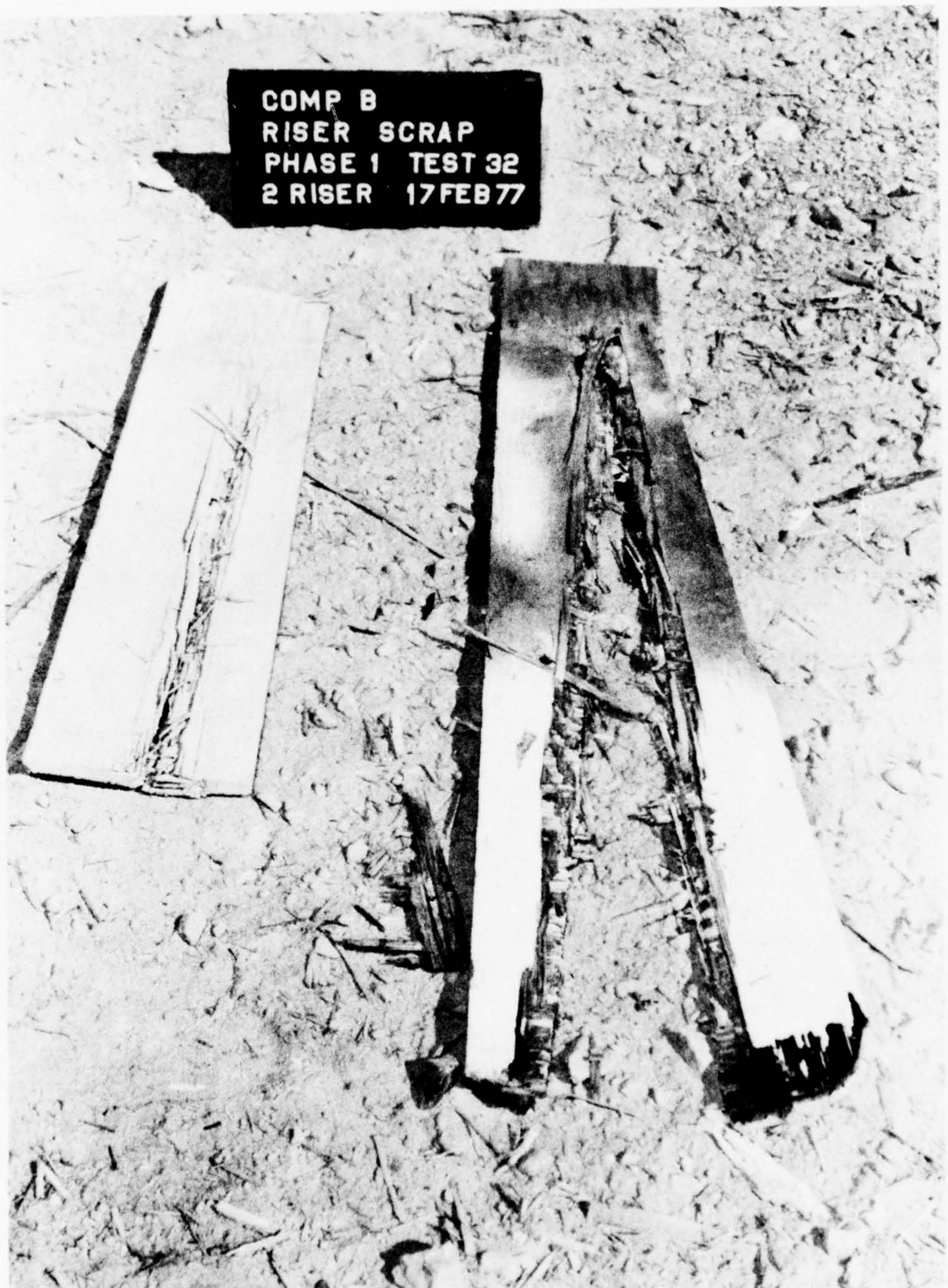


Fig 5 Witness board results, propagation detonation check tests

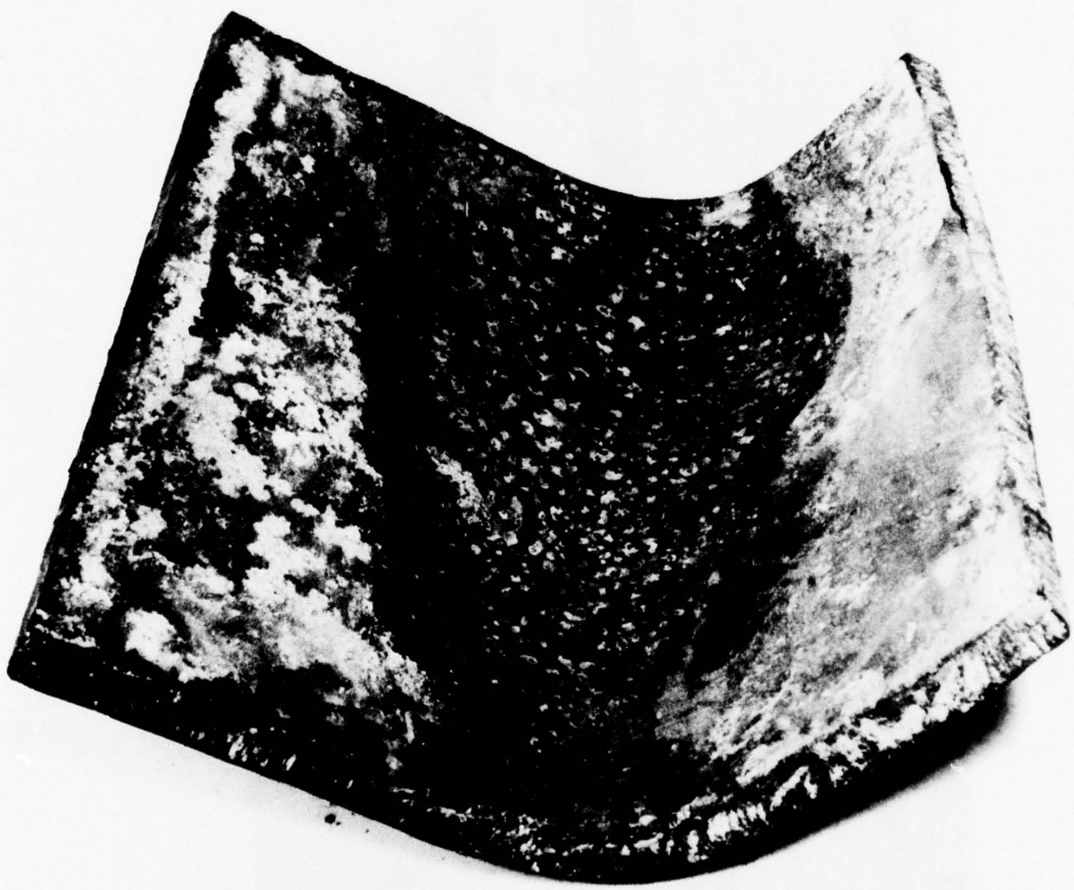


Fig 6 Steel witness plate results, propagation detonation check tests

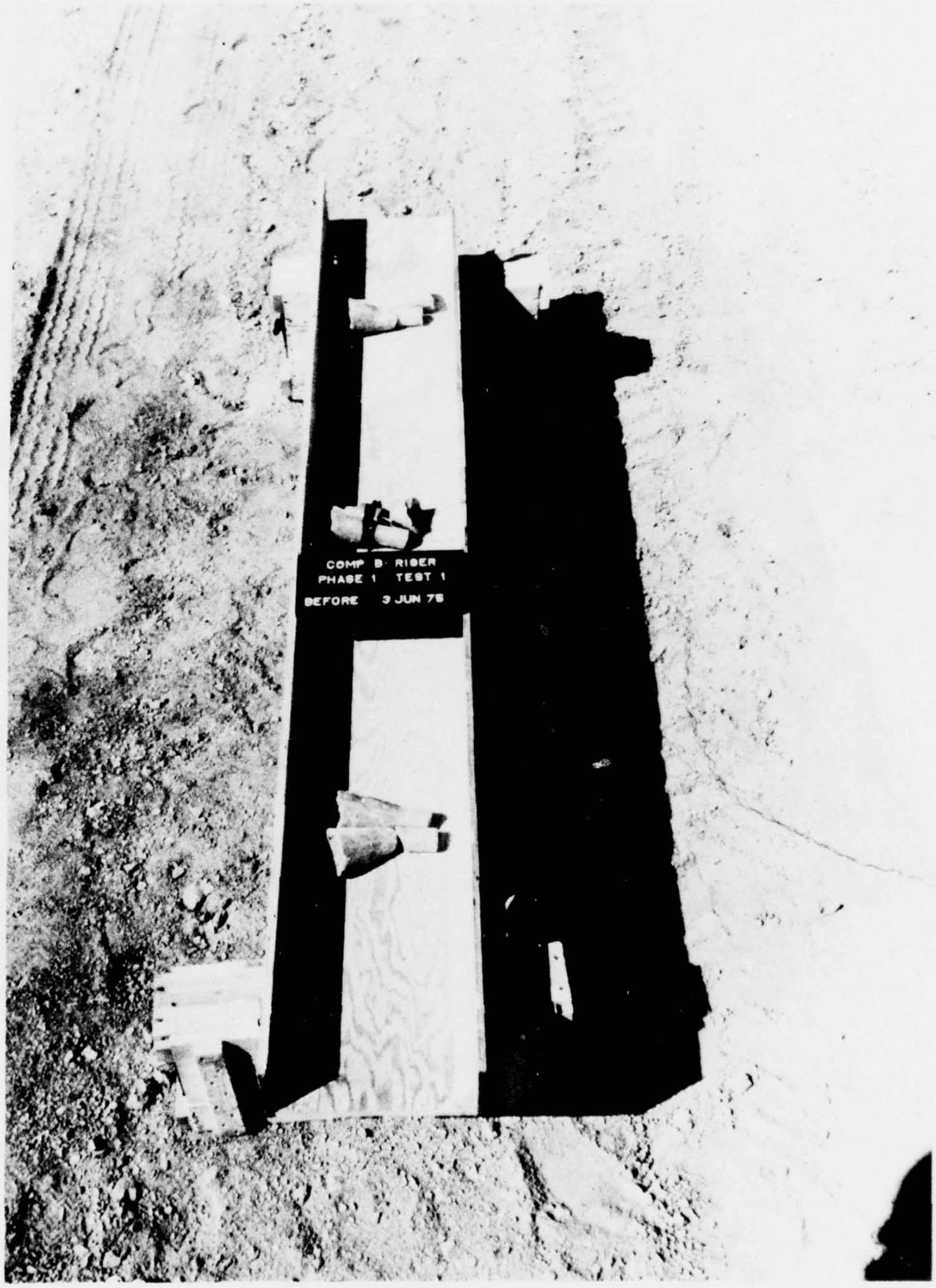


Fig 7 Test set-up without cleats, Phase I - 2 risers without funnels

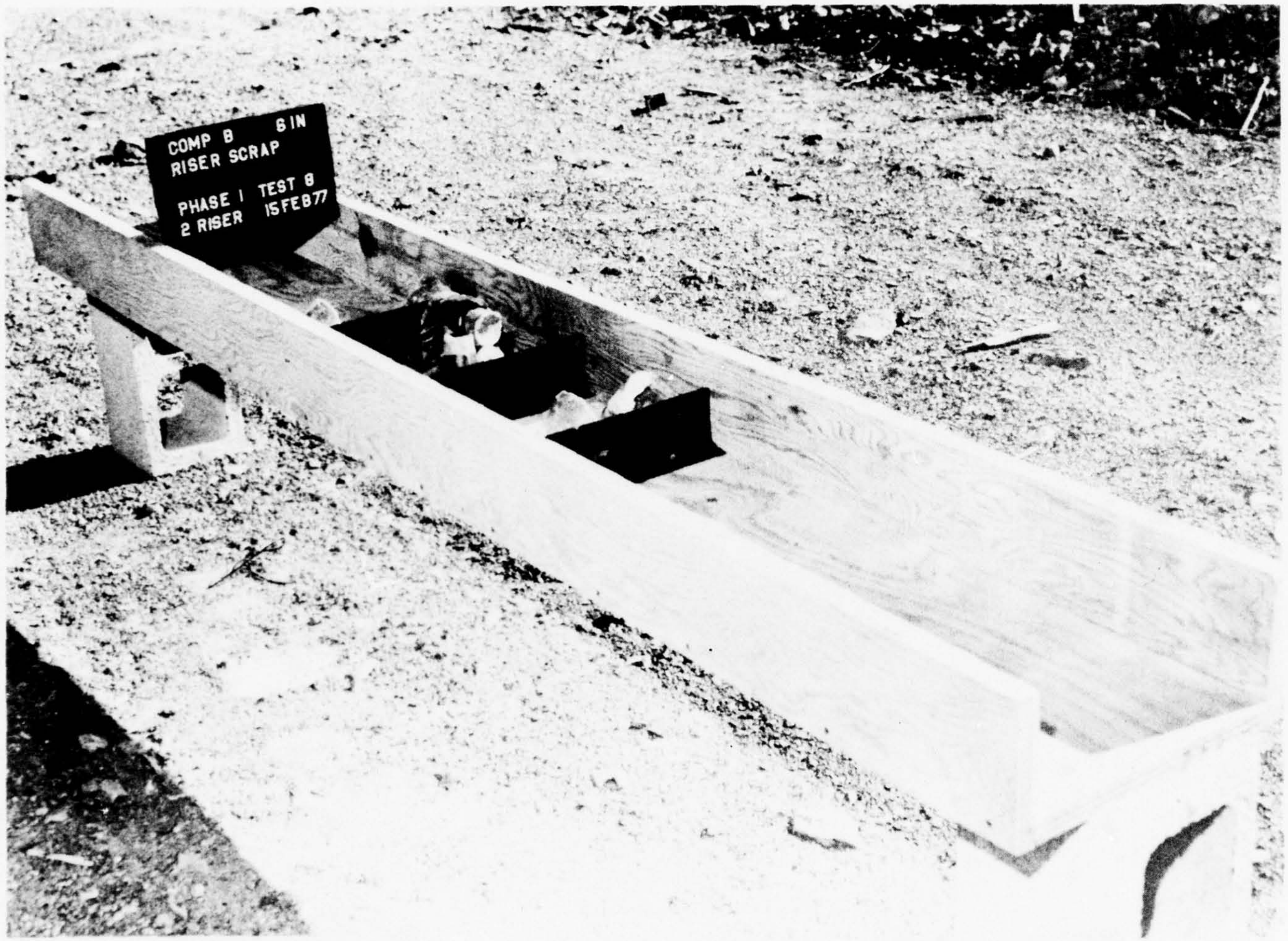


Fig 8 Test set-up with cleats, Phase I - 2 risers without funnels

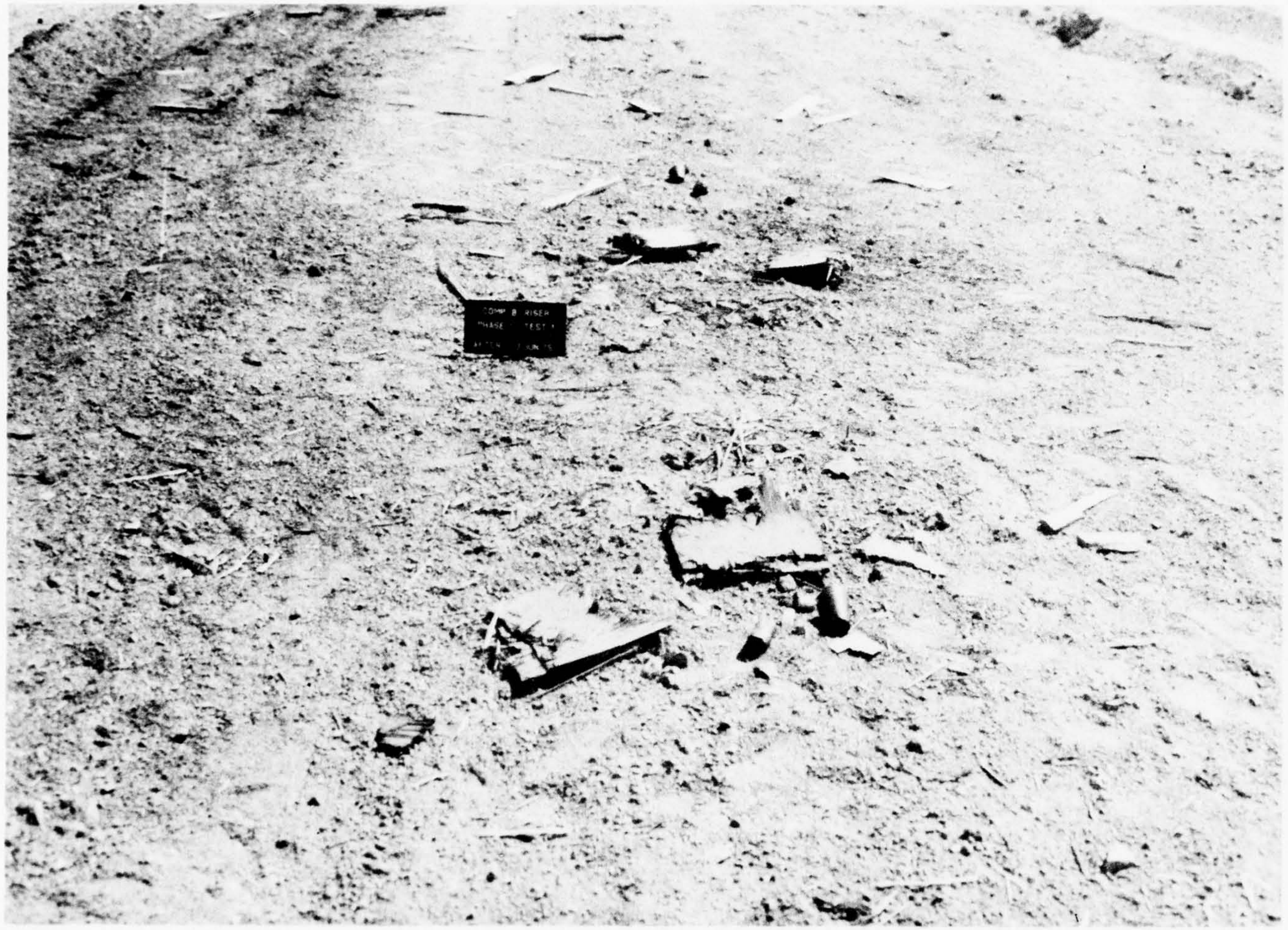


Fig 9 Post test results, Phase I -
2 risers without funnels

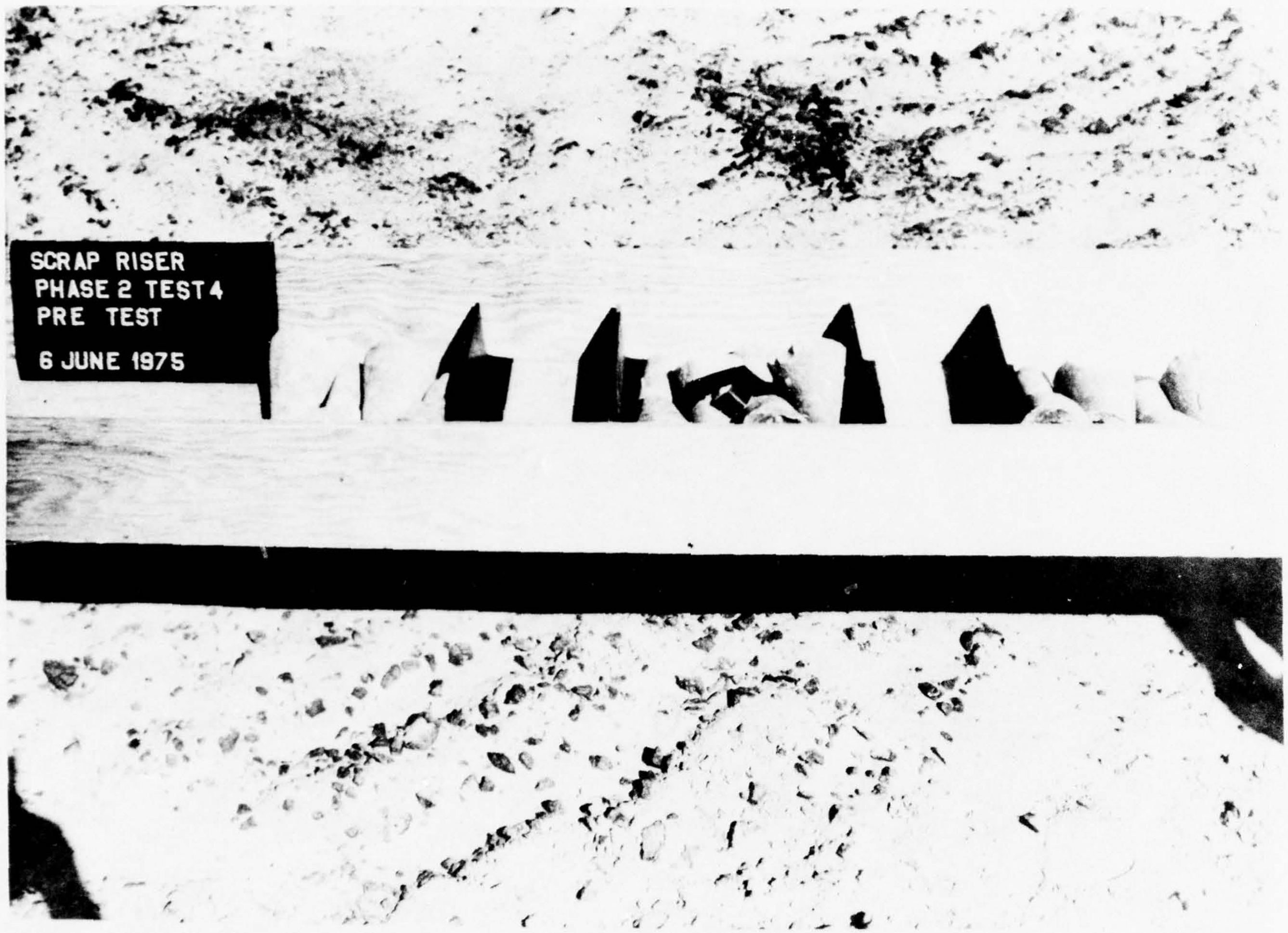


Fig 10 Test set-up, Phase II -
4 risers without funnels

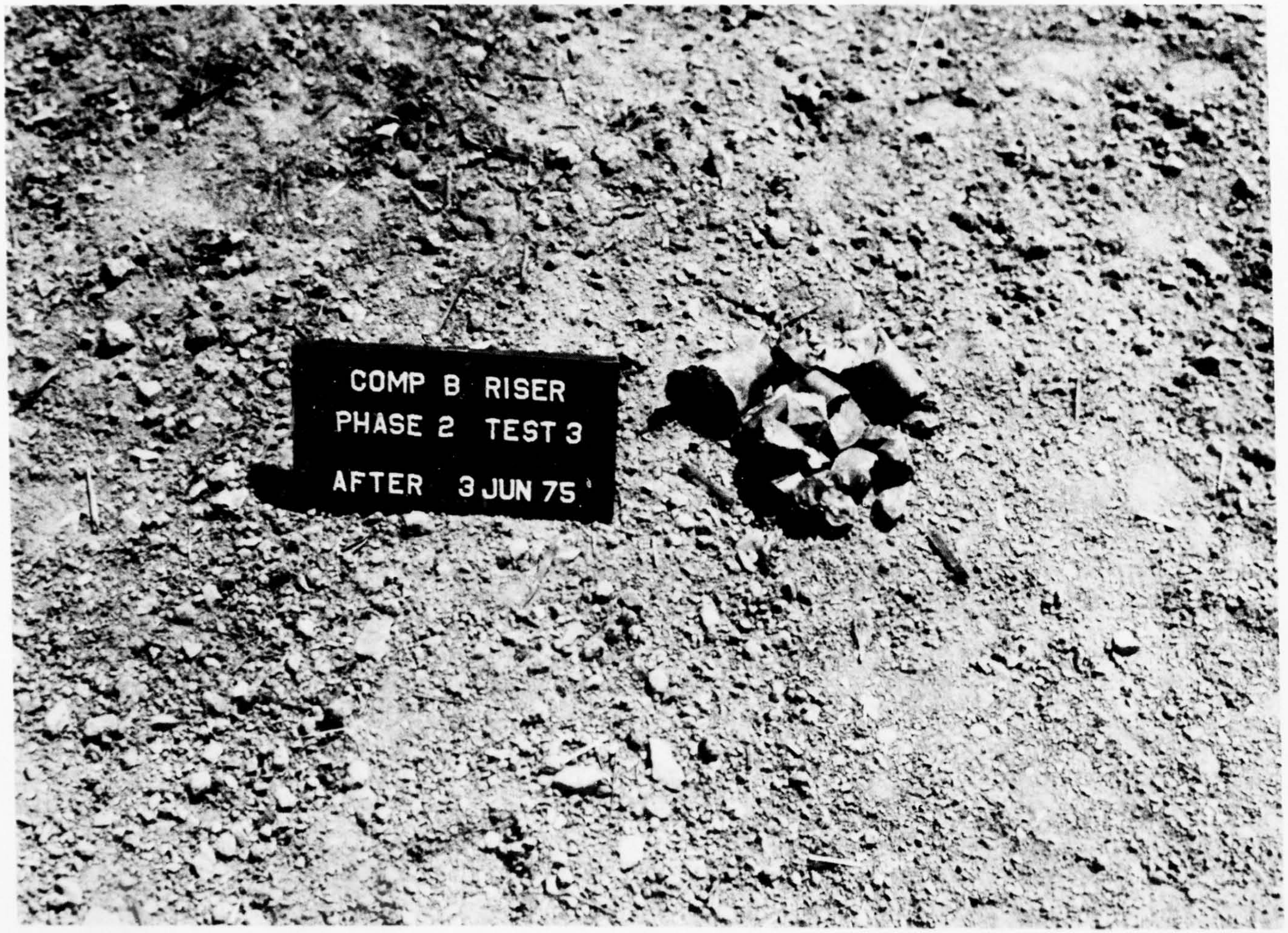


Fig 11 Post test results, Phase II - 4 risers without funnels

Fig 12 Test set-up, Phase V - 2 risers with funnels

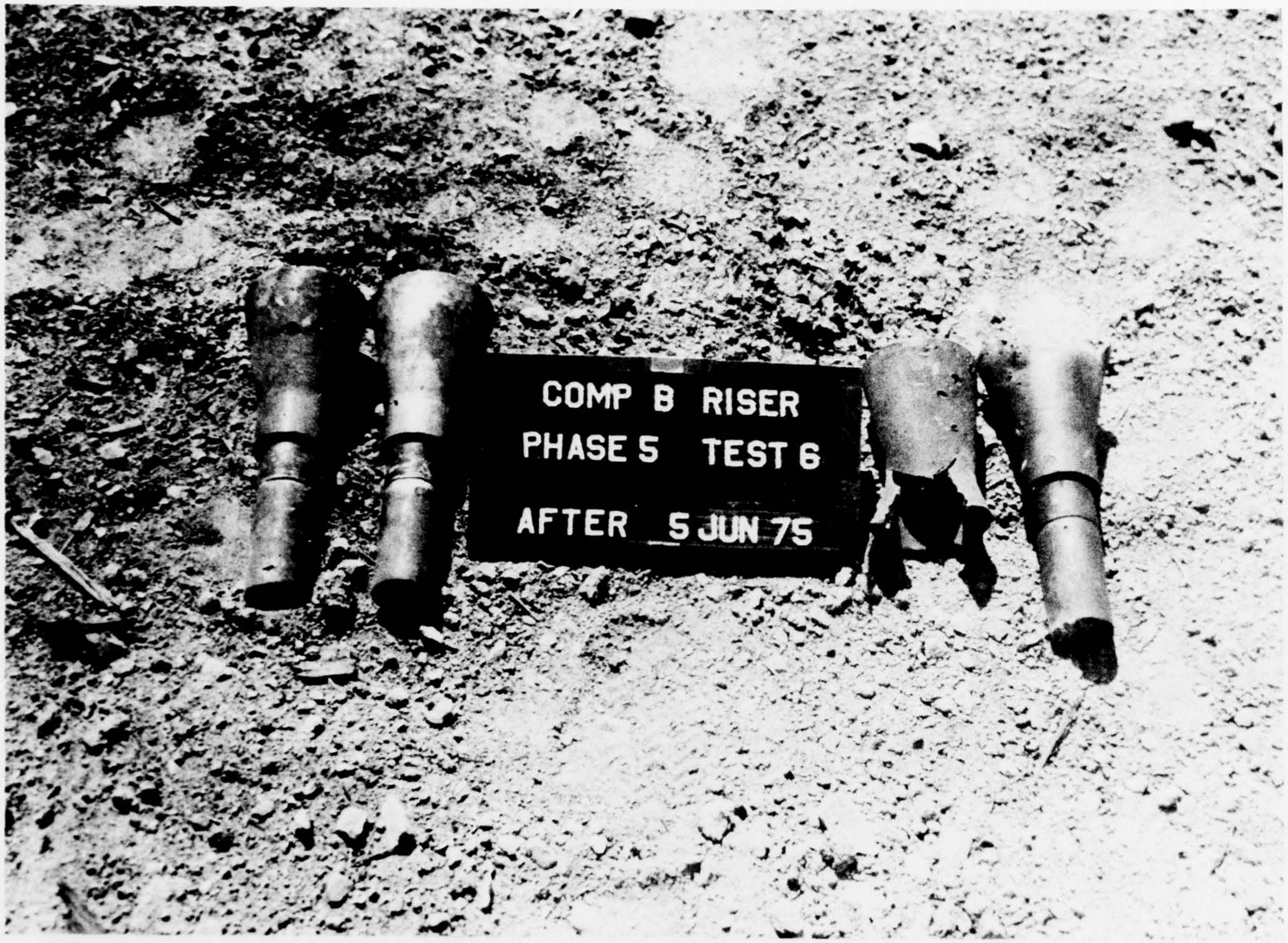


Fig 13 Post test results, Phase V -
2 risers with funnels

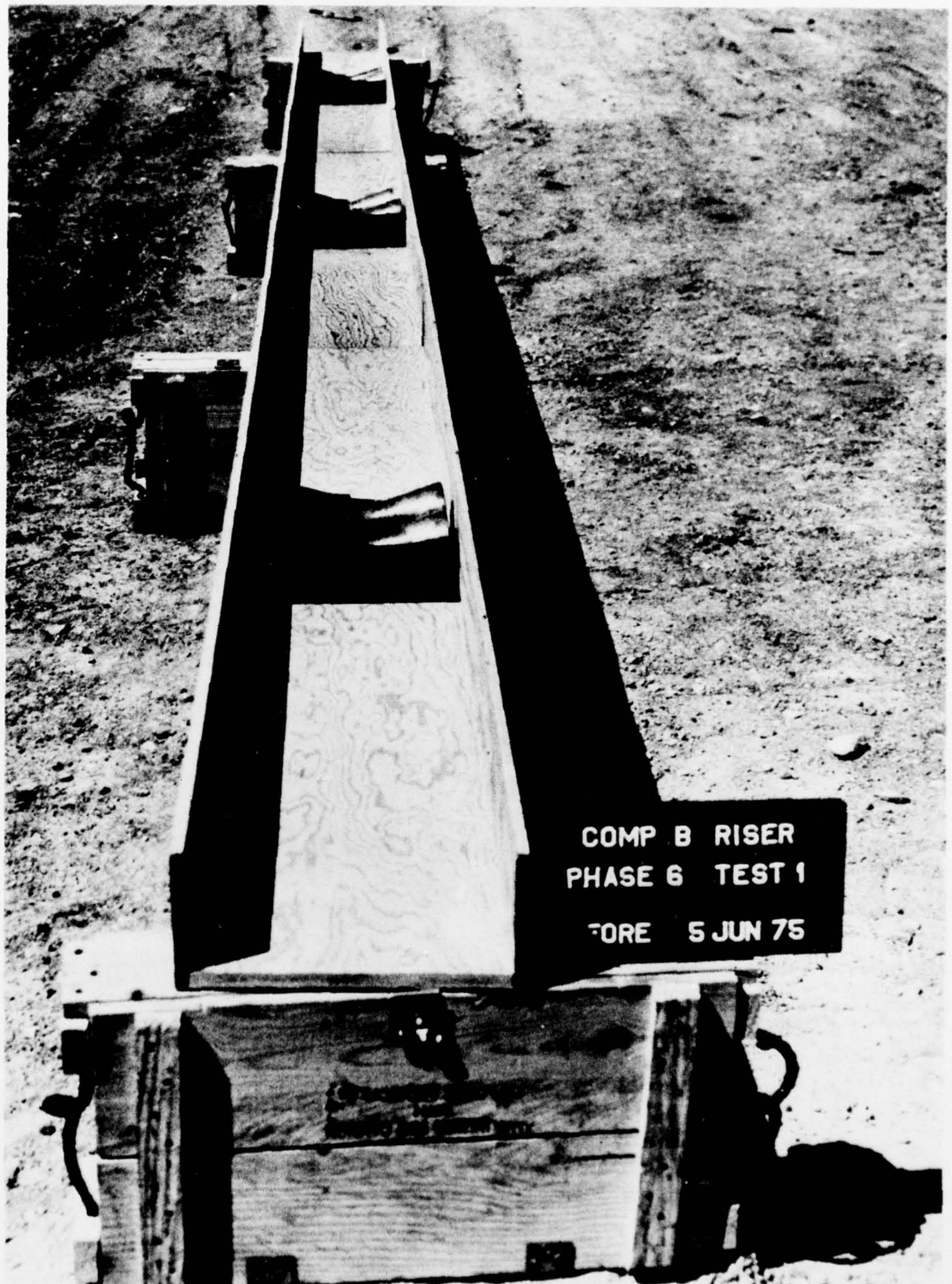


Fig 14 Test set-up, Phase 4 risers with funnels

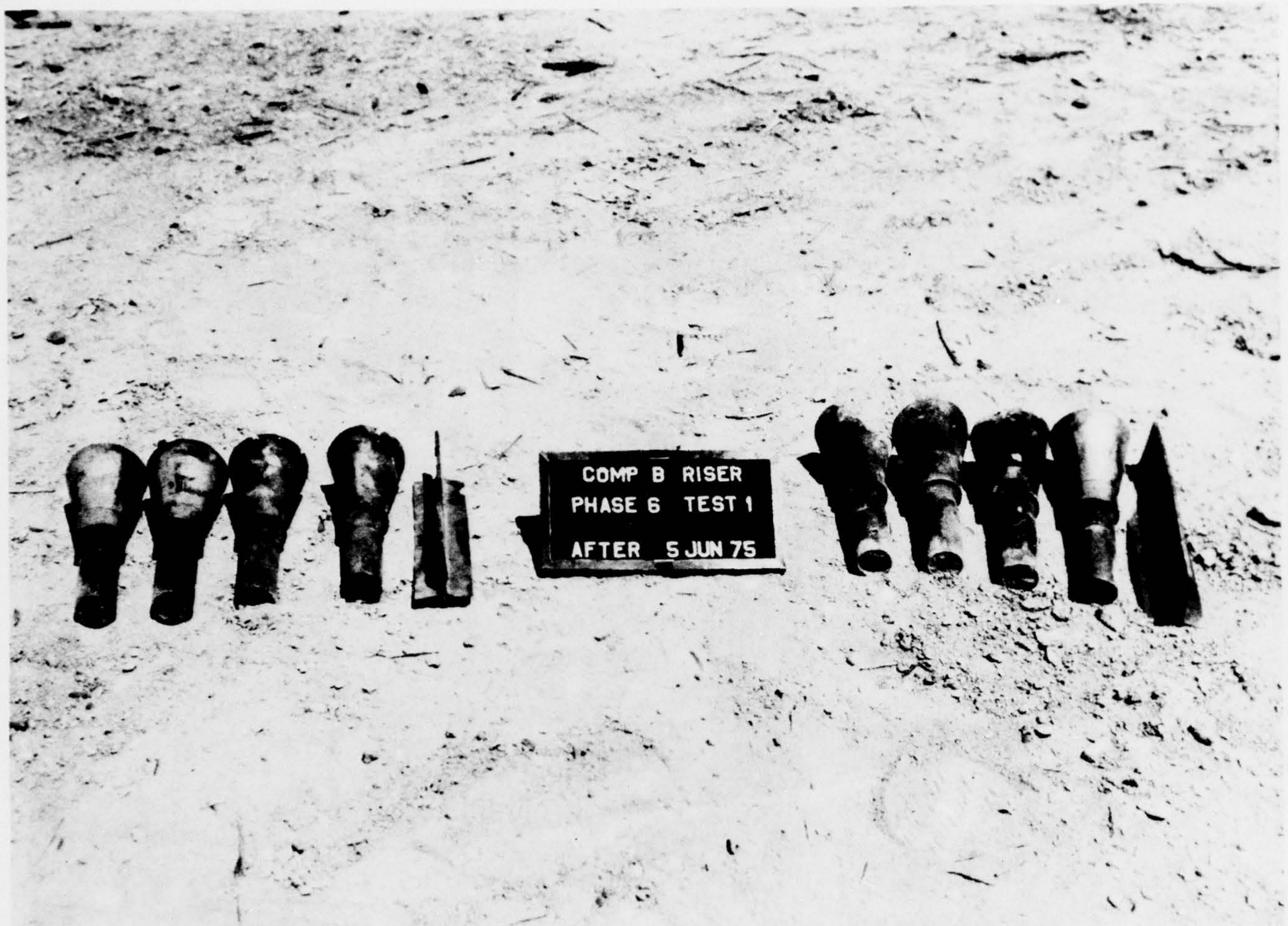


Fig 15 Post test results, Phase VI - 4 risers with funnels

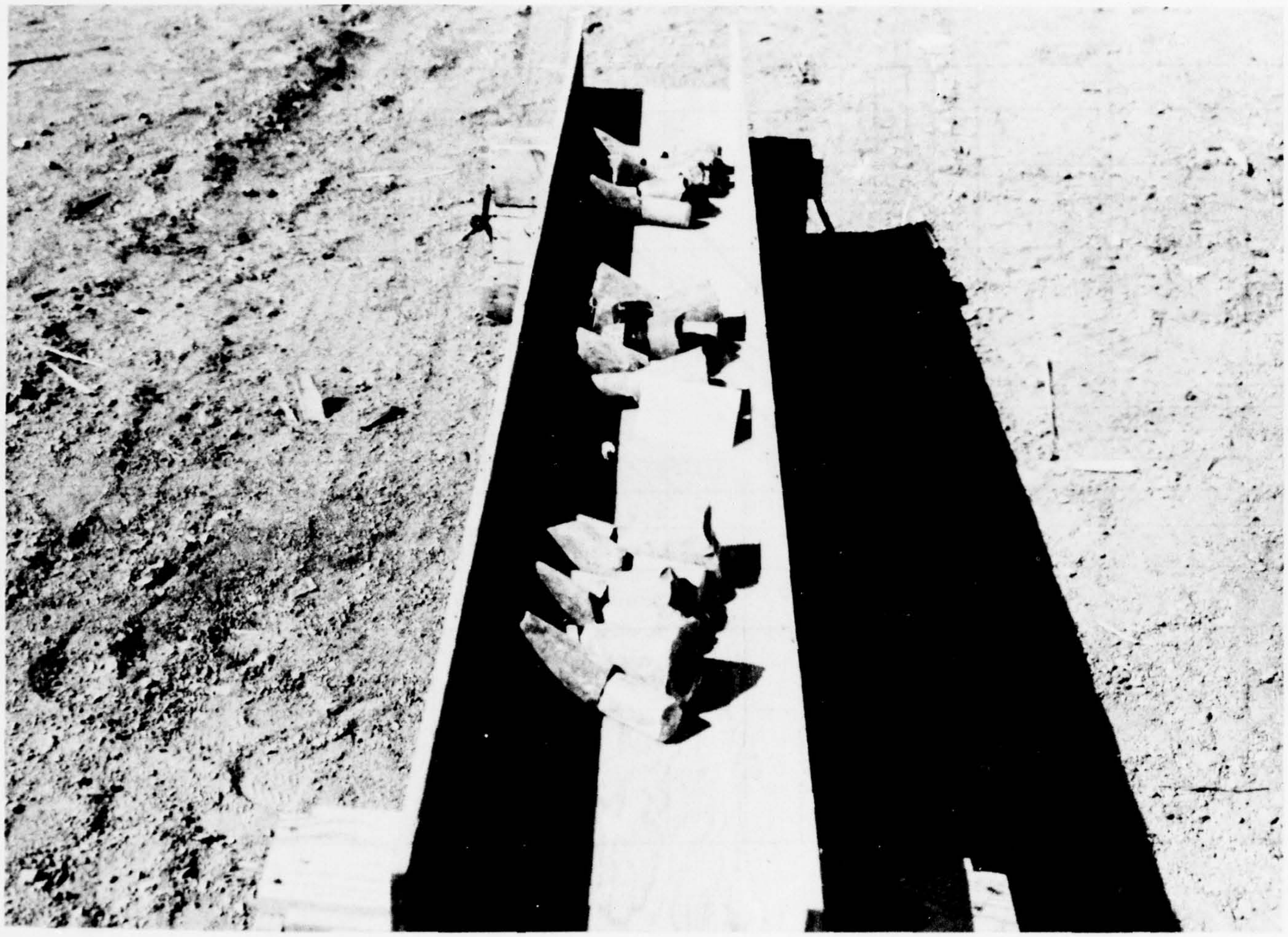


Fig 16 Unprogrammed test series, 6 risers without funnels

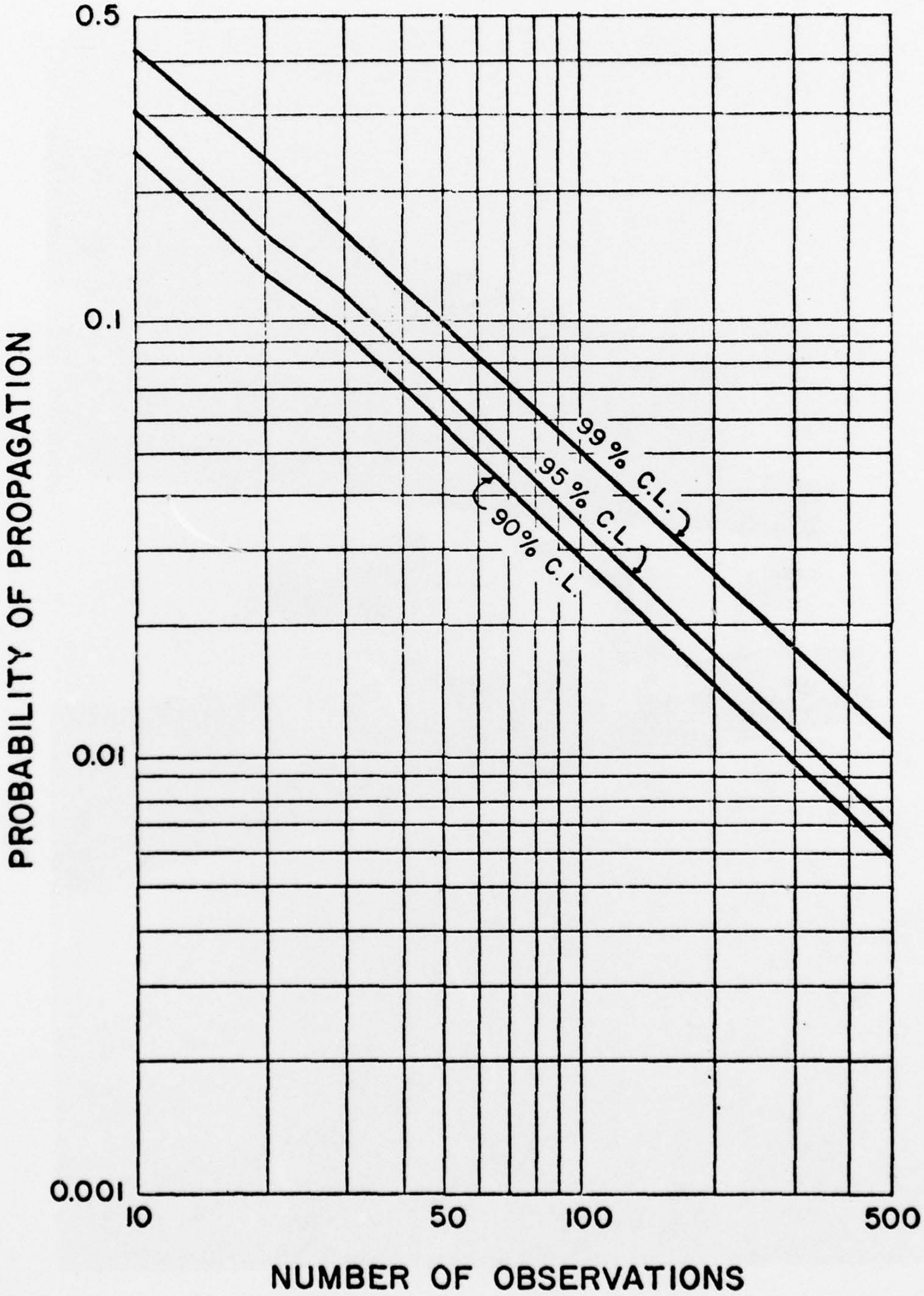


Fig 17 Variation of propagation probability versus number of observations as a function of confidence level

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

Statistical Theory

Attempt has been made in the main body of this report to evaluate the possibility of the occurrence of explosion propagation based upon a statistical analysis of the test results. This section of the report is devoted to mathematical means by which the statistical analysis was performed.

The probability of the occurrence of an explosion propagation is dependent upon the degree of certainty or confidence level involved and has upper and lower limits. The lower limit for all confidence levels is zero; whereas the upper limit is a function of the number of observations or, in this particular case, the number of acceptor items tested. Since each observation is independent of the others and each observation has a constant probability of a reaction occurrence (explosion propagation), the number of reactions (x) in a given number of observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by:

$$p = x/n \qquad \text{Eq. 1}$$

and, therefore, the expected value of (x) is given by:

$$E(x) = np \qquad \text{Eq. 2}$$

Each confidence level will have a specific upper limit (p_2) depending upon the number of observations involved. The upper probability limit for a given confidence level α, when a reaction is not observed, is expressed as:

$$(1 - p_2)^n = \varepsilon \qquad \text{Eq. 3}$$

where $\varepsilon = (1 - \alpha)/2$ and $\alpha < 1.0$ Eq. 4

Use of Equation 3 is illustrated in the following example:

Example

Determine the upper probability limit of the occurrence of an explosion propagation for a confidence level of 95 percent based upon 30 observations without a reaction occurrence.

Given

Number of Observations (n) = 30
Confidence level (α) = 95 percent

Solution

1. Substitute the given value of (α) into Equation 4 and solve for ε:

   $\varepsilon = (1 - \alpha)/2 = (1 - 0.95)/2 = 0.025$

2. Substitute the given value of (n) and value of (ε) into Equation 3 and solve for p_2:

   $\varepsilon = 0.025 = (1 - p_2)^{30}$

   or

   $p_2 = 0.116$ (11.6 percent)

Conclusions

For a 95 percent confidence level and 30 observations, the true value of the probability of explosion propagation will fall between zero and 0.116; or statistically, it can be interpreted that in 30 observations, a maximum of 3.48 (0.116 x 30) observations could result in a reaction for a 95 percent confidence level.

Probability Table

Table A-1 shows the probability limits and the range of the expected value E(x) for different numbers of observations. Three confidence limits, 90, 95 and 99 percent, are used to derive the probabilities.

TABLE A-1

Probabilities of Propagation for Various Confidence Limits

Number of Observations	90 percent	C.L.	95 percent	C.L.	99 percent	C.L.
n	p_2	E(x)	p_2	E(x)	p_2	E(x)
10	0.259	2.59	0.308	3.08	0.411	4.11
20	0.131	2.62	0.168	3.36	0.233	4.66
30	0.095	2.85	0.116	3.48	0.162	4.86
40	0.072	2.88	0.088	3.52	0.124	4.96
50	0.058	2.9	0.071	3.55	0.101	5.05
60	0.049	2.92	0.060	3.6	0.085	5.10
80	0.037	2.96	0.045	3.6	0.064	5.12
100	0.030	3.0	0.036	3.6	0.052	5.2
200	0.015	3.0	0.018	3.6	0.026	5.2
300	0.010	3.0	0.012	3.6	0.018	5.4
500	0.006	3.0	0.007	3.5	0.011	5.5

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